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UNITED STATES

NAVAL AIR MISSILE TEST CENTER

PT. MUGU

CALIFORNIA

TECHNICAL MEMORANDUM NO. 86

THE ETCHED CIRCUITRY PROCESS

COPY NO. A

SEPTEMBER 1953

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THE ETCHED CIRCUITRY PROCESS

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BUREAU OF AERONAUTICS

SEPTEMBER 1953

FOREWORD

The U. S. Naval Air Missile Test Center was established at Point Mugu, California, by the Secretary of the Navy (SecNav ltr Op-24/mad Serial 1873P24 dtd 17 September 1946) effective 1 October 1946. It is an activity of the ELEVENTH Naval District. The Bureau of Aeronautics exercises management and technical control over this activity.

The primary mission of the Naval Air Missile Test Center is the testing and evaluation of guided missiles and their components. NAMTC is assigned cognizance over all facilities at Point Mugu, California, and outlying facilities on San Nicolas Island and the Santa Barbara Channel Islands, collectively referred to as the Sea Test Range.

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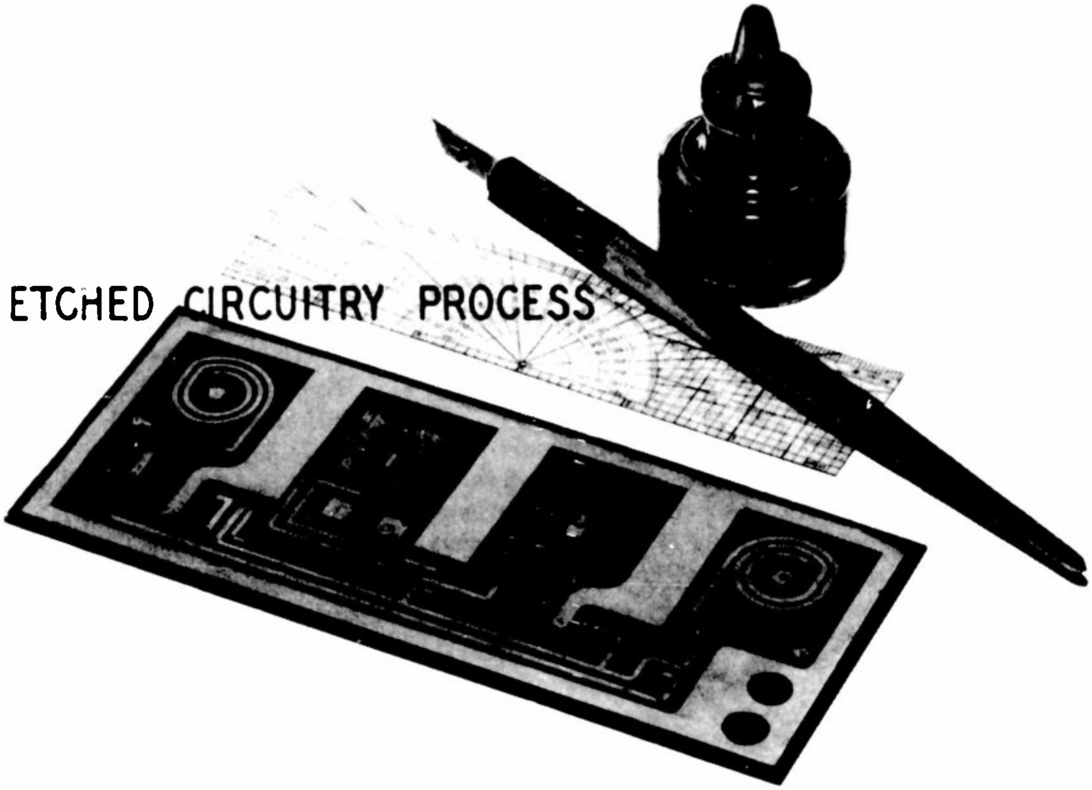
THE ETCHED CIRCUITRY PROCESS



SUMMARY

In the guided missile field, miniaturization of components is of importance, and simplicity or reduction in bulk are essential to the reliability of guided missiles and to economy in their testing.

This report describes the Etched Circuitry Process as used at the U. S. Naval Air Missile Test Center and represents an effort to effect a practicable and important contribution toward the support of the Center's mission, i.e. the testing and evaluation of guided missiles and their components.

INTRODUCTION

The complexity of electronic instrumentation in guided missiles makes necessary as much miniaturization of equipment as possible. Reduction of bulk and weight in components contributes to the general reliability of a missile. Space and weight limitations in missiles are stringent because of numerous electrical and electronic devices installed for reception of guidance signals, operation of mechanical flight controls, and transmission of data back to ground stations.

When miniaturization of electronic components began, the problem of wiring and solder assembly of subminiature components was introduced. Methods used were slow, tedious, costly. Such methods also resulted in wiring errors and accidental short circuits.

Printed or etched circuitry, produced on metal/plastic laminate plates, solves this problem.

In the Etched Circuitry Process, the desired conductive pattern is produced by etching away portions of the metal that are not part of the circuit pattern. Such etched circuits and inductances, combined with associated subminiature tubes, resistors, and capacitors, meet performance requirements and improve reliability margins. Appreciable size and weight reductions are effected. Over-all reliability is increased, and a more economic system of wiring is achieved.

In the Discussion that follows, the methods and techniques of the Etched Circuitry Process as used at NAMTC are described in detail.

DISCUSSION

The following sections of the Discussion outline the "cold top enamel process," by which a total of approximately eight or ten plates a day may be produced by one person. This process is advisable where the needs of an individual or activity are limited.

Circuit Design

Circuit drawings intended for reproduction by etching should be done under the supervision of qualified electronic personnel. The circuits should be designed, if possible, to occupy one side of the plastic plate, but it will often be necessary to use both.

Costs increase with the number of sides required. Any effort made to reduce the latter will be compensated for by less cost. The cost of producing a circuit the conductors of which are on both sides is about three times the cost of a circuit with conductors on one side.

Finished Drawing

After preliminary arrangement of conductors, a finished circuit drawing must be made. This circuit drawing should be done on white drawing board. Illustration board, with black India ink, is a suitable medium. The black represents the electrical conductors. Large areas that need black may be brushed in. The drawing should contain no gray areas. Gray-shaded areas often appear in a negative as thin, slightly transparent areas and cause faulty photoengraving.

The finished circuit will be no better than the drawing submitted for camera reproduction. All portions of the design that require close tolerances for functioning, such as inductances, need careful attention.

The drawing should be four or five times larger than the finished circuit. This will minimize drafting imperfections and make the the work of inking easier (see figure 1).

A circuit design is reproduced as a pattern of resist on a thin sheet of metal laminated to plastic. A circuit is produced by allowing etching fluid to dissolve the uncoated portions of the metal plate.

In the dissolving of the unprotected metal, the etching fluid attacks the edges of the coated portions and undercuts the edges of the circuit pattern. The depth to which the pattern will be undercut will approximately equal the thickness of the metal. If the metal plate is 0.003 inch thick, the edges of the circuit pattern will be undercut approximately 0.003 inch. The width of a conductor, undercut from both sides, would be reduced by a total of about 0.006 inch. In drawing conductors that must be held to close tolerances, the draftsman should increase the thickness of the line by an amount that would be equivalent to approximately 0.006 inch on the final negative.

Preparation of the Negative

A copy camera is used to photograph the finished drawing. The film is of the photo-mechanical, high-contrast type (see Appendix, "Photography"). Economy is effected by use of a large composite negative when a number of circuits of the same design are to be reproduced simultaneously.

Such a negative may be prepared in either of two ways:

1. The drawing may be photographed repeatedly and the resulting negatives taped together with transparent tape;
2. Positive transparencies can be produced by contact printing from a single negative, then taped together, and a large single negative reproduced by contact printing, preferably with a vacuum printer.

In composition of the negative, sufficient space must be provided around the circuits to allow them to be cut neatly. When circuits are designed to appear on both sides of the plate, negatives for the opposing sets must be adjusted to achieve correct register in the final plate.

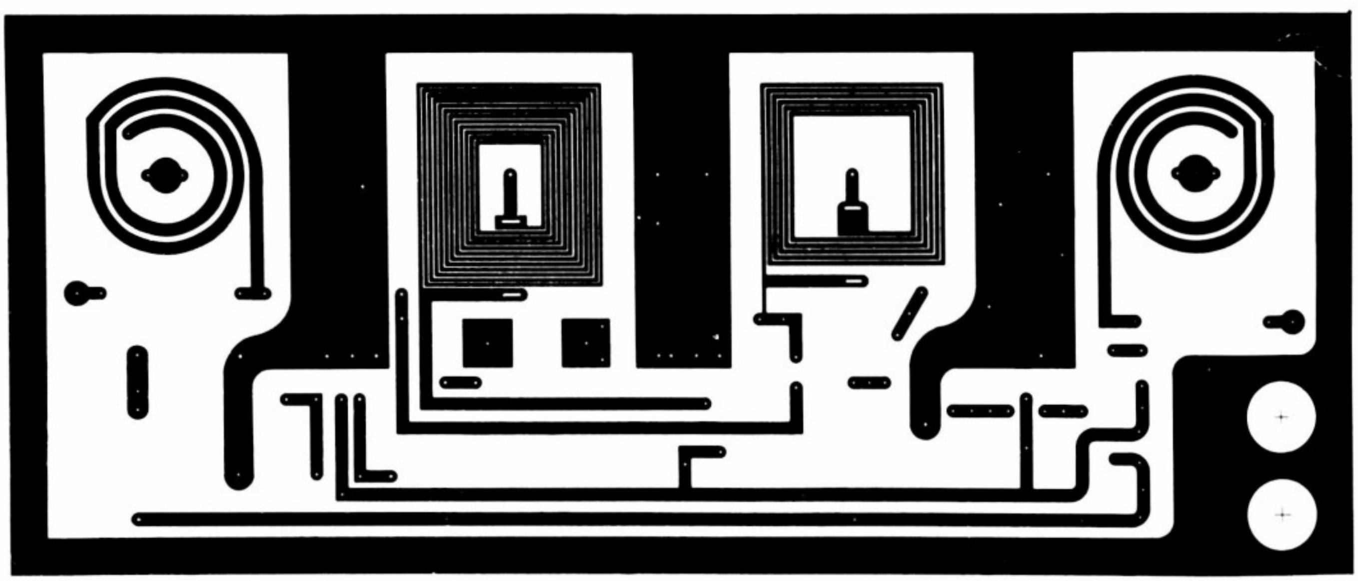


Figure 1. Finished Drawing of a Circuit.

Preparation of the Metal/Plastic Laminate Plate

Metal/plastic laminate, as supplied by the manufacturer, may have a paper protective sheet adhering to its surface. The operator should remove this paper just prior to use, and clean off all traces of adhesive with a solvent. The plate should be scrubbed with a pad of cotton that has been soaked in water, squeezed out, and dipped into powdered pumice stone (grade 4F) (see figure 2).

Figure 2. Cleaning and Graining the Plate.

Such scrubbing should be continued until the surface assumes a grained look. The plate is best cleaned by gripping it with pliers and avoiding contact with fingers. When water drains evenly from the plate, which will indicate the absence of any grease or oil, the plate should be flushed under a water tap while a fresh pad of cotton is being rubbed across the surface to remove all traces of pumice stone (see figure 3).*

The plate is next coated with photoengraver's cold top enamel, a light-sensitive coating. (All such work with light-sensitive coatings must be done is subdued lighting, for example, a 25-watt bulb.)

Figure 3. Flushing the Plate Free of Pumice Stone.

The plate, still wet from flushing, should be held on the palm of the hand with one end slightly lowered. A quantity of enamel should then be poured across the plate at the upper end, allowing it to flow to the lower end and off the plate (see figure 4).

Figure 4. Coating the Plate With Cold Top Enamel.

*Chemical baths for degreasing have been found to be unnecessary.

As the enamel flows, the plate should be rocked slightly to insure that all portions are covered. This first coat primarily flushes away the remaining water. A second coat is applied, and the plate rocked in such manner as to cause enamel to cover the entire plate completely. The coating must be free of all defects, such as bubbles or bits of dried enamel.

The plate is then placed on the whirler. From a low-speed start, the tempo should be increased to between 80 and 100 rpm, meanwhile heating the plate. Ten minutes of whirling and heating is usually sufficient. The heating of the plate should not be carried to a temperature above 120° F, otherwise difficulty may be experienced during development. Overheating will produce a top that will not develop. No bad effects from underheating have been noted at NAMTC. (A description of the properties and and handling characteristics of photoengraver's cold top enamel can be found in the Appendix, "Resists.")

Inspection of the coating for defects must be made. This can be done by holding the plate in a horizontal position slightly below eye level and allowing dim light to be reflected off the surface. Grainy or insufficiently coated areas will become visible. When the surface appears glossy and smooth, and resembles a coating of colorless lacquer, the coating is satisfactory.

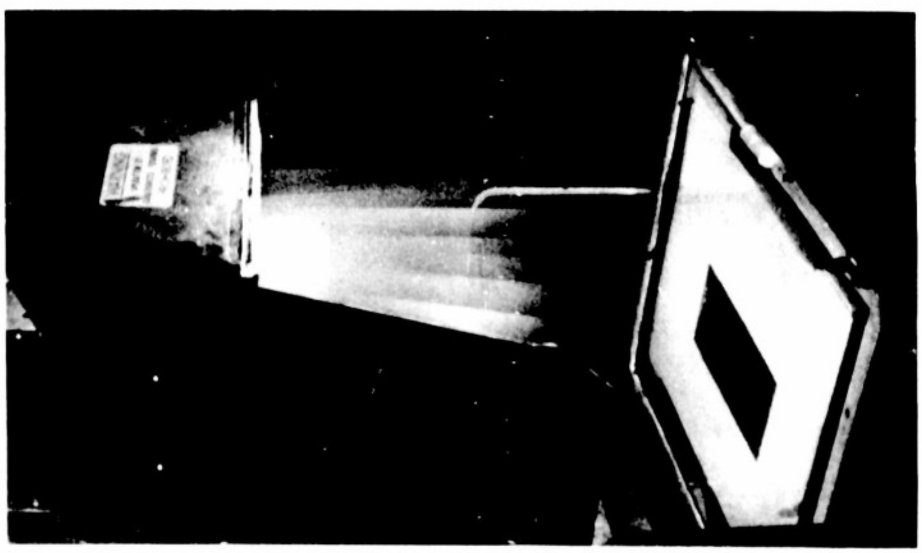
If prismatic colors are seen, the coating is too thin; if it is deep amber in color, the coating is too thick. A few bad spots may be corrected later. Thickening at the edges of the plate may be ignored since it is usual to use plates that are about an inch oversized.

The plate is then allowed to cool to room temperature.

Reproduction of the Image

The plate, coated side up, is placed in a vacuum printing frame. The negative of the desired circuit is placed with its emulsion side next to the coated surface. The frame is then closed and vacuum applied. The plate is exposed to the light source - usually a carbon arc - for 5 to 8 minutes, depending on the thickness of the coating (see figure 5). If the image is washed away in development, the exposure may have been insufficient. Prolonged exposure will produce no ill effect provided that the black areas of the negative are opaque.

Figure 5. Exposing the Plate to Carbon Arc.



The plate is developed by placing it on a level surface and pouring sufficient developing solution over it to cover the surface (see figure 6). The plate should be rocked gently during development, and fresh developer added if any indications of drying appear. The rocking motion will spread the developer and aid in the developing action. The developer will dye the exposed areas and dissolve the unexposed areas. Developing time will vary between 30 seconds and 3 minutes, depending on the time that the enamel supply bottle has been open (see Appendix, "Resists").

The plate is next subjected to a gentle flow of cold water from a tap to remove developing solution and dissolved enamel. The remainder of the unexposed but undissolved enamel may be removed by an extremely light swabbing of the areas with a pad of cotton (see figure 7).

Figure 7. Cleaning the Plate After Development.

Figure 6. Pouring Developer Over the Plate After Exposure.

At this stage, the enamel image is delicate, especially if a fresh solution of enamel was used, and care should be exercised in swabbing. Images produced from older solutions are better able to withstand rough treatment.

The plate is then allowed to dry at room temperature.

The next step is to heat the plate to 230-250° F in a controlled-temperature oven for 10-15 minutes. This heating makes the image resistant to the etching fluid by:

1. Causing the shellac to melt and flow over pinholes, and
2. Driving off moisture, which would allow the etching solution to penetrate to the metal.

The plate is removed and allowed to cool (without forcing) to room temperature.

Any remaining areas of unprotected metal plate that are not to be dissolved away must be "stopped out". An example is the back of the plate if a portion of the circuit is later to be placed there. "Stopping out" is done by painting the metal with shellac to which has been added about 3 ounces per gallon of violet aniline dye.

At this point, an inspection should be made of the entire circuit, and any imperfections in the protective coating corrected with the

shellac. A size 00 or 0 red-sable water-color brush or script brush, used with a lamp and magnifying glass, is suitable.

After being "stopped out" and allowed to dry, the plate is ready for etching.

Etching Time

The time required to etch away the uncoated areas of the prepared plate varies with the temperature, concentration, and composition of the etching solution. Raising of the solution temperature decreases the time required for etching. A solution temperature increase from 70 to 120° F will increase the etching time to less than half. Temperatures above 120° F should be avoided because of possible damage to the resist. The concentration of etching solution also influences the etching time. The rate of etching increases with decreasing concentration of the etching solution. Weak solutions tend to attack the protective coating.

Exact etching times cannot be stated because of the variables involved. An average of 30 minutes will be required to etch to a depth of 0.003 inch in a bath of 40 degrees Be at 120 degrees F with a low copper content (one-half ounce of dissolved copper per gallon of solution).

Solution Warming

The temperature of the etching solution may be raised by means of a hot water bath. The tray containing etching solution is supported inside a larger tray. Hot water from a hose is run into the outer tray and allowed to drain off over the edge of the tray (see figure 8).

Etching Procedure

The operator should place the plate, supported by etching clamps, in the etching solution with the design side downward. This position is best for rapid etching because the material being removed settles to the bottom of the tray instead of being deposited on the etched surface, which would slow further etching.

Figure 8. Plate Being Placed in Etching Fluid.

When the plate has been in the etching solution for 15 or 20 seconds, it should be removed and inspected for scum. Scum prevents etching action and shows as a bright area against a dull, etched background. The presence of scum on a plate is not always obvious before etching, but it will generally appear as a thin violet stain outside the areas covered by the resist. Removal may be delayed until after etching has begun. Rub the plate gently for a short time with a pad of cotton dampened with an acetic acid/salt solution (see Appendix, "Rottenstone") dipped in rottenstone, then rinse and replace in the etching solution. The general process should be repeated until all areas show a dull tone (see figure 9). This will indicate that etching is taking place in the desired areas.

Figure 9. Removing Scum With Rottenstone.

The plate must be inspected during etching to determine if unwanted etching is taking place. If so, the plate should be removed from the etching solution, rinsed under the water tap, and allowed to dry. The operator should then "stop out" the areas with shellac and, after the shellac is dry, replace the plate in the etching solution. If the plate is not thoroughly wetted under a water tap before immersion in the etching solution, the solution may "pull away" from certain areas and cease etching action.

This etching must be continued until all unprotected metal areas are removed.

Cleaning of Plates

When etching is complete, the protective enamel and shellac should be cleaned off the circuit. The "stopping-out" shellac may be removed by immersing the plate in lacquer thinner and scrubbing the surface with a stiff bristle brush.*

The enamel is removed by scrubbing the plate with a damp wad of cotton dipped in pumice stone (grade 4F). Scrubbing should be continued until the metal areas are clean and bright. Certain liquid enamel removers exist, but these often fail to remove the enamel completely and are usually toxic.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the application of the Etched Circuitry Process to guided missiles is a definite contribution to their efficiency and reliability. Large number of guided missile parts must function in series. A short circuit in a single component can cause failure in a guided missile.

The Etched Circuitry Process as outlined in this report provides a more economical and reliable method of prefabricated wiring, and tends to eliminate faulty soldering, wiring errors, accidental short circuits, and other fabrication difficulties, many of which could cause failure of a guided missile flight. In-series functioning of components is thus aided, and the number of devices which by individual failure could cause the loss of a missile is thereby reduced.

It is to be recommended that the process described in this report be used for prefabricated wiring in guided missiles in cases where a limited number of circuits is needed, or where quantity production is not essential to the needs of the activity.

Where it is essential to mass-produce standard circuits, it is recommended that the process of placing the resist on the plate by silk-screen method, or offset lithography, be used. This would eliminate the time element involved in use of cold top enamel.

By cold top enamel process, a total of about eight or ten plates a day can be produced by one person. Five hundred plates a day may be produced via silk-screen process; by offset lithography, several thousand plates per day.

The work done thus far at the U. S. Naval Air Missile Test Center has been of an experimental nature as a support function toward better test and evaluation techniques.

*If a circuit is to occupy both sides of a plate, the second half to be produced may be brought into register with the first by drilling a .013-inch hole (No. 80 twist drill) through the center of the register marks, which may be seen as crosses in the upper right and lower left corners of the drawing (see figure 1). The process of cleaning, coating, whirling, and heating is repeated for the reverse side of the plate. The negative for the reverse side is carefully brought into register over the holes by means of a corresponding set of register marks on the negative for the reverse side. The negative may be held in place by means of Scotch tape. The process of exposing, developing, heating, stopping out, etching, and cleaning is repeated.

appendix

PROCESS DETAILS AND MATERIALS

Metal/Plastic Laminate

Metal/plastic laminate can be obtained from printing supply firms in varying thicknesses of plastic or metal. The usual metals employed are aluminum and copper. Copper generally lends itself to smoother etching. Metal may be bonded to one, or to both sides. Metal thickness ranges from 0.0015 to 0.009 inch. The operator should avoid using a thickness greater than is necessary to produce the desired results.

The time of etching increases with the thickness of metal and undercutting increases proportionally. For most circuits, satisfactory results may be obtained with 0.003-inch metal.

Resists

Photoengraver's cold top enamel is suitable as a light-sensitive coating for etched circuits. This enamel is a purified, degreased shellac rendered light-sensitive by the addition of ammonium dichromate. Mixing it in the shop is more expensive than buying it commercially, but for informational purposes, the following formula is given:

Heat 50 to 60 grams of purified degreased shellac with 75 milliliters of ammonia (d 0.91) and 250 milliliters of water until dissolved. Treat the solution with 70 milliliters of 3 per cent ammonium dichromate solution and dilute with 100 milliliters of 90 per cent alcohol. Plates coated with this solution are light-sensitive.

It is not recommended that any attempt be made to mix these chemicals since more uniform and dependable solutions are obtainable commercially through firms who have been constantly perfecting old formulas under carefully controlled laboratory conditions which are usually not available to, or practical for, the shop.

Cold top enamel is obtainable in gallon jugs from graphic arts supply dealers. It is good practice to filter the cold top enamel through a plug of cotton placed in a glass funnel and inserted into an easily handled, narrow-necked bottle. Use of a brown glass bottle is recommended. This will protect the solution from strong light.

Work on light-sensitive coatings should be done under subdued light, for example, a 25-watt bulb. A sufficient quantity, as may be required for the day's use, should be filtered into the bottle. Cold top enamel should not be poured back into the jug once the enamel has been removed. Spoilage of the entire amount may result if a portion becomes contaminated. The enamel can be spoiled by allowing tap water to mix into the solution; chemicals used for purification may be present.

Difficulty may be had in development if solution from a freshly opened bottle of cold top enamel is used. Parts of the image area often wash away completely. This is because fresh cold top enamel tends to produce very delicate images. To prevent this, the freshly opened bottle should be aged a few days before use. An aging process begins when the bottle is opened and continues until the solution is unfit for use. The process is slow and several months will pass before the solution produces unsatisfactory tops. Such tops will be indicated by many pinholes or cracks that appear during development or when "burning in" the image.

Other Light-Sensitive Resists

Other resists are commonly employed in photoengraving. Albumen, glue, and gelatin

have not been found suitable for the process of making circuits.

The burning-in temperature required to transform such solutions into good resists is higher than the plastic can withstand. A gelatin sensitizer was tried, but did not produce the results obtained with good enamel. Resists other than cold top enamel are not recommended for this particular method of circuit making.

Photography

The finished drawing will be photographed by a copy camera that produces a reduced negative. This type of camera must not be confused with the conventional, portrait-type camera. Process lenses, used in copy cameras, are corrected to produce a flat field over a given area. The substitution of other cameras for this work may result in failure. Graphic Arts shops producing negatives for the offset method of printing usually have suitable copy cameras.

The type of film to be used should be of the photomechanical high-contrast variety not ordinarily stocked in the photographic laboratories of Naval Establishments. The film requires special developers. A suitable film is the Photomechanical Orthochramatic Type 2, listed as items 615 through 631 of the Aviation Supply Office Catalog, Class 18 Photographic Equipment and Supplies, Section 1801, of November, 1949. A good developer is also found as item 1617, stock number E51-D-118-600, in the same catalog.

It is not possible to give exposure time and detailed information concerning development. These factors vary for different cameras, lighting, and accessory equipment. Where a copy camera is not available, negatives may be obtained from commercial photoengraving companies. It will be necessary to furnish them finished drawings and information concerning the dimensions of the desired image on the negative.

Rottenstone

Rottenstone must be prepared for removing scum in the etching process. Large grains, which would scratch the resist, are generally present in the rottenstone. It is necessary to separate such grains from the smaller, useful grains. This is done best by precipitation.

A quantity of rottenstone should be placed in the tall glass vessel and water added. Thorough stirring will cause the large grains to settle. After the settling process is complete, the surplus water is to be drawn off and the upper two-thirds of the rottenstone removed with a ladle. The grains at the bottom must not be disturbed. The mixture will then be placed in a separate vessel, such as a beaker, and provided with a lid to exclude foreign matter.

The mixture should not be allowed to dry out. It will be necessary merely to wet a wad of cotton, squeeze it out, and dip it into the mixture. The wad is then ready for use. A good solution to use in conjunction with the rottenstone is:

Water	20 ounces
Common table salt	4 ounces
Glacial acetic acid	2 ounces

This solution will be used in place of water for dampening the cotton wad.

Ferric Chloride

No health hazard has been detected in the use of ferric chloride solutions. The only effect produced by immersion of the fingers in this solution is a brown stain. Although the solution attacks most metals, it has no effect on organic materials other than to produce these brown stains.

No acids should be added to the solution. No benefit will be derived, and detrimental effects may result, particularly if nitric or hydrochloric acid is added.

Solutions of ferric chloride may be obtained from dealers, and are supplied in carboys ready for use. If the solution is prepared in a shop, a sufficient quantity of lump ferric chloride should be added to ordinary tap water to bring the solution to 42° Bé.

The solution may be heated over a burner in a suitable vessel to hasten dissolving of the lumps.